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Introduction to Biofuel

1.1 Introduction

1.1.1 Need of Emerging Technology

Food, water, clothing and shelter are the traditional basic needs of humans. However, today we rely on electricity and transportation like we do on food and water. Electricity and transportation are such an essential part of our modern life that we cannot imagine today what life would be like without it. Even if we radically decrease transportation to that firmly wanted to ensure basic needs, humans can still certainly survive, but this would need a profound re-modelling of anthropoid activities such as economic and social. An upcoming scenario where human actions are not excessively unnatural is likely more tolerable. These amenities come with a need, i.e. fuel to run and this fuel is usually from the fossils of animals and plants buried millions of years ago. Fossil fuels have facilitated our civilisation everywhere. The major energy source for today's world is fossil fuels [1]. Fossil fuels have been driving the world for eras, making them economical and dependable since the infrastructure is previously in place for their sustained use. Since the early nineteenth century, the fossil fuel consumption in the world has almost doubled every 20 years. The advantage of fossil fuels is their ability to produce huge quantities of energy in just a single location. Innovation of the world's energy system must be on the horizon in current worldwide conditions that have led to a collective awareness. The development and advancement of nations worldwide is also dependent on the fossil fuel industry. The significant driver of the fossil fuel industry in its vast expansion over the course of several decades is the political and economic support [2]. The technical advancement in the technologies related to energy conversion to produce heat, electricity and transportation fuels has made a striking impact on society.

Being non-renewable resource, its overconsumption will apparently result in serious environmental issues [2]. Several consequences have already been observed on the habitat from the burning of fossil fuel, which releases noxious gases such as carbon dioxide, carbon monoxide, sulphur dioxide and nitrogen dioxide [3]. Fossil fuel is estimated to account for one-third of global energy utilisation and is responsible for 15 and 31% of global CO₂ and O₃ man-derived emissions, respectively [4]. Acid rain is one of the major consequences of

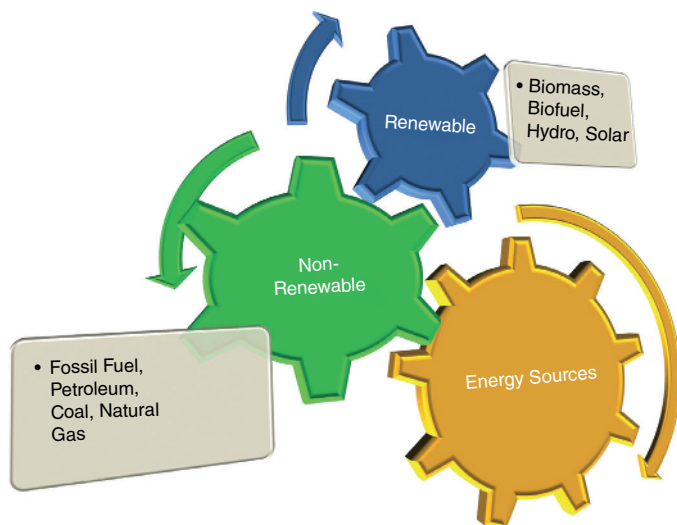


Figure 1.1 Sources of energy.

these gases, which damages the crops, lakes, rivers, trees, wildlife statues and architecture. The consequence of global warming can be reversed and halted with making a shift to clean energy sources. Change to clean can be achieved with the renewable energy fuel (biofuel) that is formed by current processes from biomass rather than geological processes from the formation of fossil fuels (Figure 1.1). Thus, there has been a recent prerequisite to research and thereby to develop advanced energy alternatives that are feasible contenders having the potential to alleviate the matters of climate variation and energy security.

1.1.2 Renewable Energy

Renewable energy sources are the resources that can be replenished as quickly as they are utilised. Some of the main renewable energy sources are solar, biomass and wind. With the use of renewable energy sources, some of the environmental, social and economic problems can be omitted since these resources are environment friendly, with very little release of consumed and toxic gases. Since these resources can be used again and again to produce convenient energy, renewable energy is going to be a significant basis for power generation in the future [5, 6]. A total of 15–20% of the entire world's energy is provided by different renewable energy resources, such as hydropower, wind, solar, biomass, ocean energy, biofuel, geothermal, etc. The chief barriers to the progress of renewable energy are cost, market share and policy [7, 8]. Some of the unique properties of renewable energy resources are that they have the capacity to meet the world's energy demand, offer energy security and protect the atmosphere.

The most utilised non-fossil fuel in today's world which serves as a substitute for engine fuel is bioethanol. Oil being the world's prime source of energy and chemicals, the present demand is about 12 million tonnes per day (84 million barrels a day) with a projection to increase to 16 million tonnes per day (116 million barrels a day) by 2030 [9–11]. The world

leaders in biofuel development and usage are United States, Sweden, Brazil, France and Germany. On a worldwide scale, the United Nations (UN) International Biofuels Forum is formed by Brazil, China, India, South Africa, United States and the European Commission [12, 13].

Three percent of the global fuels for road transportation is provided by biofuel [14]. Worldwide biofuel production reached 161 billion litres (43 billion gallons US) in 2019, which was up by 6% from 2018. In the direction of reducing reliability on petroleum by 2050, International Energy Agency (IEA) wants more than a quarter of world demand for transportation fuels to be filled by biofuel [15]. To reach IEA's target annually, global biofuel productivity has to surge by 10% from 2020 to 2030. Only 3% growth/year is expected in the coming few years. However, the production and consumption of biofuels are not on track to meet the IEA's sustainable development scenario. By 2024, nearly 154 billion US dollars is projected to grow in the market for alternative fuels. IEA recorded that the ratio of development and deployment of renewable energy is getting to be deployed, which should be clogged to obtain net zero climate goals using different policies and subsidies [16].

Presently, bioenergy is the major renewable energy source worldwide and more than two-thirds of the renewable energy mix is accounted for with these resources. One can continuously produce biofuels by growing biomass feedstock repeatedly that can withstand indeterminate human exploitation. Biofuels and bioproducts over the previous few years have been produced by biomass, which is one of the renewable resource derivatives of biological precursors [17, 18]. Biofuel is one of civilisation's utmost vital renewable energy sources as well as storable, contrasting conventional fossil energy. Microalgae are being assumed to be the greatest attractive basis for the production of biofuels, amid all these living organisms utilised.

Renewable energy is the leading emergent energy source, which has grown to 90% in the past 20 years [19]. Cost, demand, policy decisions, feedstock availability and public acceptance are the various factors that affect the renewable energy deployment [20].

1.2 History of Biofuel Development

Ever since humans discovered fire, charcoal, woodchips and cattle dung have been used as a source of energy and still today people use these solid fuels for heating and cooking in many parts of the world. In the mid-1700s and early 1800s, oil extracted from whale was broadly used for lighting purposes. The discovery of biofuel is not very recent. In the mid-1700s and early 1800s, oil extracted from whale was largely used for illumination purposes [21]. Since the nineteenth century, transesterification of vegetable oils has been generally identified and employed. In fact, the method presently employed for the production of biofuels from biomass is the same inherited from the ancient times. The feedstock used for their production was also very analogous [22]. Peanut, hemp, and corn oil and animal tallow were conventionally utilised and have been partly substituted by soya bean, rapeseed, recycled oil, forest wastes, and trees and sugar cane. The history of biofuel is considered to be more political and economic than being technical. Ever since humans have explored fire, feedstock like charcoal, woodchips, and cattle dung have been utilised as a

basis of energy, and still in many countries around the world these solid biofuels are used for heating and cooking [23].

German named Nikolaus August Otto was the first discoverers to influence public for the usage of ethanol. In the 1860s, he ran his initial engines on ethanol, which is a fermented product of yeasts [24]. This car was completely designed to use hemp derived biofuel as fuel. In the 1880s, Henry Ford's first sample automobile could be functioned with ethanol as fuel, the 'Quadricycle' and his "Model T", the most prevalent car produced between 1908 and 1927 [25]. The first communal demo of vegetable-oil-based diesel fuel was at the 1900 World's Fair in Paris, when the diesel engine was built by Otto Company to run on peanut oil when the French government commissioned it. Diesel engine was invented by another German scientist Rudolf Diesel. His diesel engine was designed to run on peanut oil.

However, during the 1920s, due to inexpensive prices and low viscosity of the diesel engine, producers reformed their engines to petroleum-derived diesel fuel, leading to the improved atomisation of the fuel in the engine's combustion chamber [26, 27]. This problem was resolved when the Belgian patent 422,877 was granted on 31 August 1937 to George Chavanne of the University of Brussels. It designates the usage of methyl and ethyl esters of vegetable oil, attained by acid-catalysed transesterification [28], as diesel fuel, being the first report on what is today known as biodiesel.

1.3 Generation in Biofuel

Based on feedstock and method of production, biofuels are classified in different groups named as first-, second-, third- and fourth-generation biofuels [29] (Figure 1.2). The composition and calorific content of biofuel depend on the kind of biomass and process used.

In first-generation biofuels (Figure 1.3), edible biomass is used for starch and sugar, which leads to increased production cost; the utilisation of resources are inefficient; and energy is consumed in cultivating crops. Specifically, edible biomass uses a large area of crop fields for its production and requires a large quantity of fertilisers and water which leads it to compete with food crops.

The second generation of biofuels is built on more resourceful renewable substituents by employing switch grass, sawdust, low-priced woods, crop wastes and municipal wastes that are categorised under inedible lignocellulose biomass [30]. Although this generation requires more phases to generate acceptable biofuels at a viable cost, it overcomes the disadvantages of the first generation (Figure 1.4) [32].

Algae biomass is used in third-generation biofuels, which is an aquatic feedstock [33, 34]. Seaweed is the example of algae that are photosynthetic plants that capture large amounts of CO₂ and produce O₂ and oil as well. Biofuels are less stable when produced from algae than from other sources because the core reason is that oil produced is highly unsaturated making them more volatile specifically at higher temperatures. However, this kind of biomass has some disadvantages such as its huge price and the fact that they are more likely to degrade [35]. Bioengineered microorganisms such bioengineered algae or crops conquered fourth-generation biofuel. They are still in an early stage of development and are genetically modified such that they can consume a large amount of CO₂ than they emit when burned in the environment [36].

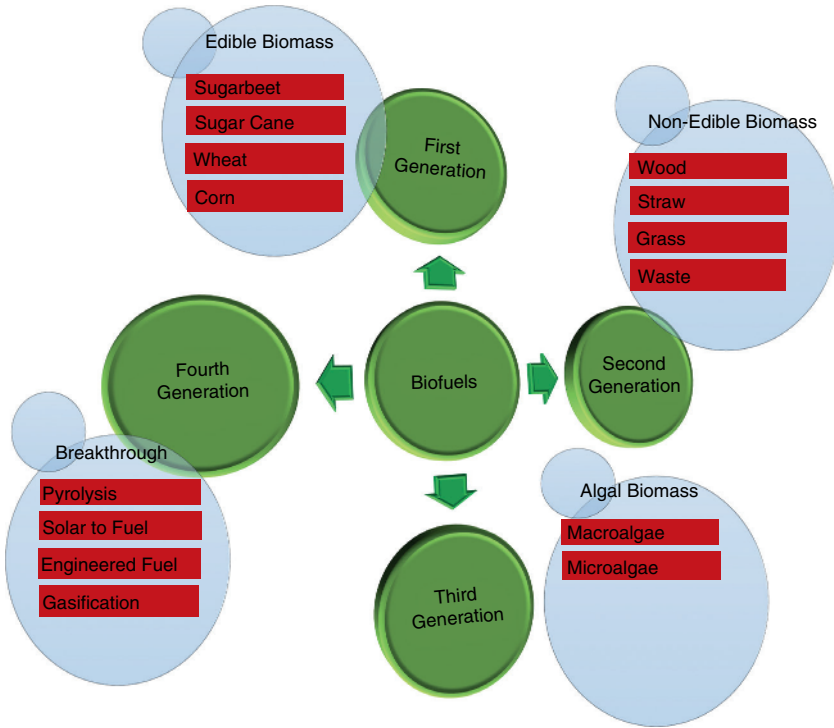
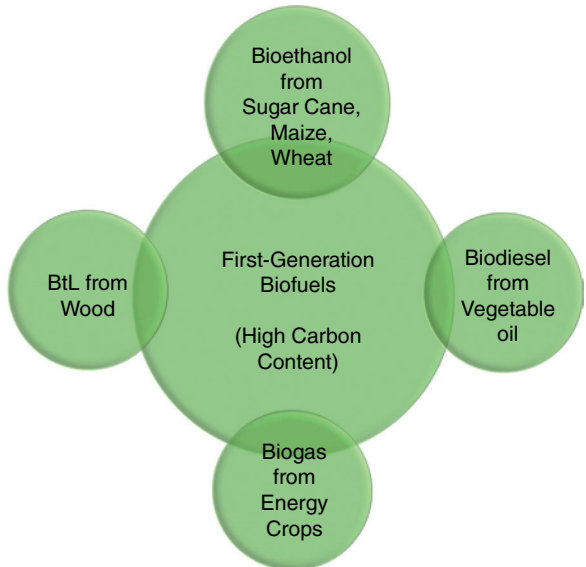


Figure 1.2 Different generation biofuels.

Figure 1.3 First-generation biofuels.



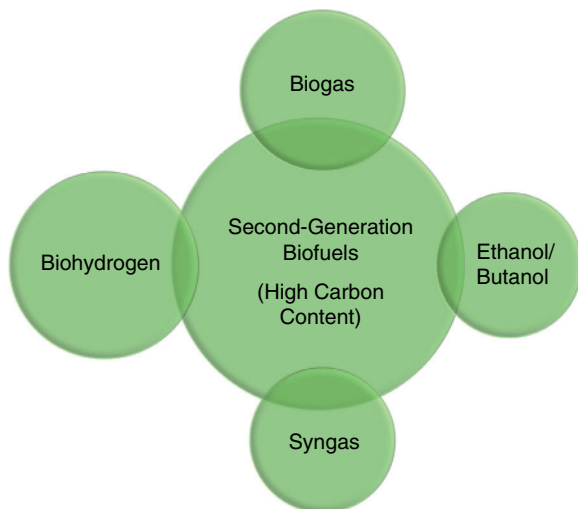


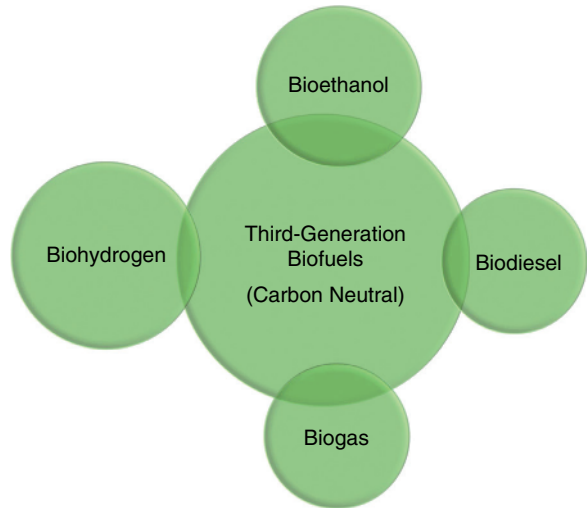
Figure 1.4 Second-generation biofuels. *Source:* Adapted from [31].

First-generation biofuels include ethanol and biodiesel and are directly related to a biomass that is more than often edible or in other terms food-related items. Concerns arose about using edible crops as feedstock and the impacts on croplands, biodiversity and food supply [37]. The emergent problems that can be observed directly were as follows:

- a) the biomass chemical composition,
- b) energy balance,
- c) availability of croplands and the contribution to biodiversity and cropland value losses,
- d) competition with food needs,
- e) cultivation practices,
- f) emission of pollutant gases,
- g) impact of mineral absorption on water resources and soil,
- h) use of pesticides,
- i) cost of the biomass and its transport and storage,
- j) soil erosion,
- k) economic evaluation considering both the coproducts and feedstock,
- l) creation or maintenance of employment and
- m) resource availability such as water.

Second-generation biofuels are defined as fuels produced from a wide array of different feedstock, [38] especially but not limited to non-edible lignocellulose biomass or non-food sources. A wide variety of abandoned materials can be used as biofuel feedstock such as agricultural waste [39], poplar trees [40], willow and eucalyptus [41], miscanthus [42], switch grass [43], reed canary grass [44] and wood [45], and they mostly consist of plant cell walls whose primary components is polysaccharides [46]. Second-generation biofuels are bio-ethanol, bio-methanol, Fischer-Tropsch (FT) diesel, dimethyl ethanol (DME), bio-hydrogen, which are a few examples of second-generation biofuels. Second-generation biofuels also generate higher energy yields per acre than first-generation biofuels [47]. The general pathway for the production of second-generation biofuel is biochemical or

Figure 1.5 Third-generation biofuels.



thermochemical [48], but as far as sustainability is considered, the following problems are incurred:

- a) feedstock is not economically and practically viable for stable energy supply due to their low conversion rates,
- b) lack of feedstock and
- c) with the ever-growing demand, various algae-based biofuels have been augmented.

The cost effectiveness of this generation of biofuels still needs development because there are several technical barriers that need to be overcome.

The third-generation biofuels are usually made up of algae or microbial feedstock (Figure 1.5). Third-generation biofuels are more energy dense than first- and second-generation biofuels per area of harvest [49]. There are two main classifications for algae based on their size and morphology: macroalgae and microalgae [50]. Microalgae have several important properties such as requiring less space to grow, high oil content, the ability to grow in both artificial and natural environments, and being eco-friendly. They also possess a unique advantage that is the capability for both oxygenic photosynthesis and hydrogen production. In addition, their growth requirements are simple and limited to light, carbon dioxide and other inorganic nutrients [51, 52].

It is considered the most energy-intensive fuel. Third-generation biofuels still have the following disadvantages:

- a) requirement of complex structure, storage and content,
- b) capital intensity of the process of third-generation biofuels,
- c) cultivation of cultures and
- d) lack of preferences during cultivation.

For a country to adopt alternative fuels, it must be able to avoid a food crisis and control measures regulating the fuel markets [53].

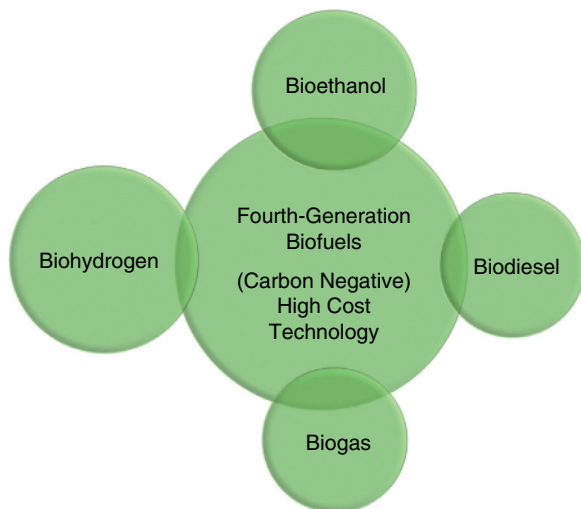


Figure 1.6 Fourth-generation biofuels.

The fourth category would include biofuels produced from biomass (Figure 1.6), whose genetic modification would additionally increase the absorptivity of carbon dioxide in the photosynthesis process [54].

This generation approach utilises metabolic engineering of algae for generating biofuels from oxygenic photosynthetic microbes and creating artificial carbon sinks. Figure 1.7 demonstrates various pathways for the production of biofuels.

1.4 Classification of Biofuels

Biofuels, as discussed, are produced from the organic materials. They can be present in any type of state and form. Thus, on the basis of the state, the biofuels can be classified as the solid, liquid and gaseous biofuels [55].

Solid biofuel includes wood, coal, dried plant material and manure. Improvement in the physical and chemical properties, i.e. particle size, moisture content and energy content, is implemented time to time. The use of solid biofuels is renewable, which can replace energy generated from fossil fuels and help to displace greenhouse gas (GHG) emissions from fossil fuels. It can also lower the risk of forest fires by managing the forest floor debris.

The main drawbacks associated with these fuels are their variable composition, high moisture content, low energy density and availability of the related resources. However, the high content of volatile matter, water-soluble nutrients, low maintenance cost and reduced harmful emission make it a preferable candidate in biofuel market [56]. The technological and other barriers can be dealt with due care in progressive modifications. Thus, renewable standardised solid biofuels offer consistent quality, leading to improved performance, lower maintenance costs and reduced emissions.

Liquid biofuels include bioethanol, dimethyl ether, bio-oil and biodiesel. A wide range of feedstock, process technologies, and field of applications are opened in this area [57].

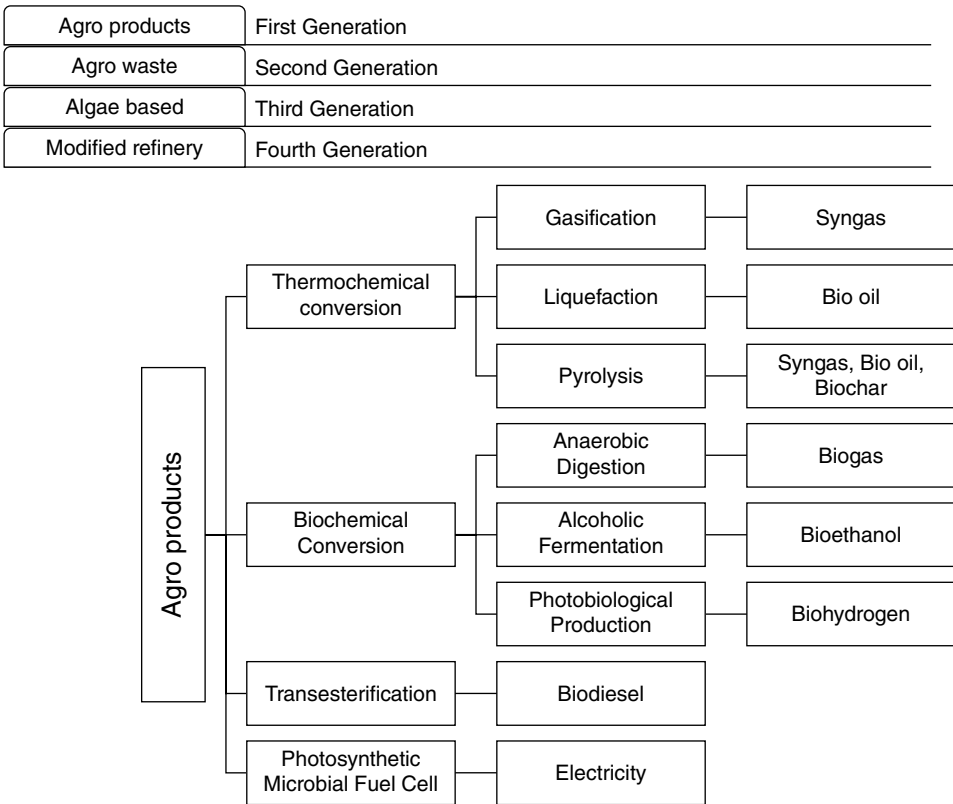


Figure 1.7 Production of biofuels.

Ethanol is a type of alcohol that can be produced by fermentation using any feedstock containing significant amounts of sugar. Ethanol can be blended with petrol or burned in nearly pure form in slightly modified spark-ignition engines. Bioethanol suffers from the disadvantage that it can degrade certain elastomers and corrode certain metals inside the vehicle, leading to the conclusion that continual replacement is needed. Most existing car petrol engines can run on blends of up to 15% bioethanol with petroleum/gasoline. Biodiesel can be derived from a wide range of oils, including rapeseed, soya bean, palm, coconut or jatropha oils using transesterification process [58–60]. Biodiesel can be used in regular diesel engines in pure form or may be blended with petro-diesel in any proportion. Sixty percent of the emission is reduced with the use of biodiesel instead of diesel. One of the problems associated with the biodiesel is that its viscosity increases with a decrease in the temperature. Thus, its use in countries with lower climate requires extra precautions while using biodiesel [61]. Industry, government and research organisations are also supporting the research activities and the related growth of liquid biofuels [62].

Major examples of gaseous biofuel include biogas and syngas. Biogas and bio-hydrogen are companionable gaseous biofuels for blending with natural gas. Usually, woody biomass is a suitable feedstock used in the production of biofuel due to its easy availability and use

of non-arable lands. The cellulose and hemicellulose divisions of wood can be used for the fermentative production of gaseous biofuels [63].

Biogas is a gas composed principally of methane and carbon dioxide produced by anaerobic digestion of biomass or by thermal processes from biomass, including biomass in waste [64]. Biogas is a blend of gases produced by the decomposition of organic matter in the absence of oxygen. Anaerobic biogas, which is comparable to landfill gas, comprises 60% methane and 40% carbon dioxide [65]. Biogas is used in power generation systems such as combined-cycle power plants. Syngas, also called a synthesis gas, is a mix of molecules containing hydrogen, methane, carbon monoxide, carbon dioxide, water vapours as well as other hydrocarbons and condensable compounds [66]. It is the main product of gasification, and the majority of products of high-temperature pyrolysis are carried on any biomass, residues and waste. Thermochemical process called gasification converts carbonaceous materials, such as biomass, municipal wastes, coal, petroleum and tyres under controlled amounts of oxidants such as oxygen, air and CO₂ inside a gasifier to obtain syngas [67]. Syngas is mainly used for the generation of heat and power in both stand-alone combined heat and power plants and also in large-scale power plants. It can also be used in internal combustion engines as fuel.

The characterisation of the biomass and selection of the feedstock have a major effect on the technology used and the application field. Thermochemical processes involved such as pyrolysis, gasification and combustion involve several steps, chemical species reactions, catalysts, and routes. To lessen the efforts, simulations and modelling need to be simplified, which will allow optimal conditions for biofuel productions [68].

1.5 Technologies Involved in Biofuel Production

The biofuel is nothing but the monoalkali ester that is derived from the animal fat or vegetable oil. These monoalkali esters are to be extracted from the feedstock, and to do so different technologies are to be employed. Some of the technologies involved in the production of biofuels are transesterification, thermochemical process, microwave-assisted synthesis [69–71], etc.

Pyrolysis of oils is a chemical change using heat in the presence of nitrogen (without participation of oxygen) to produce a wide range of different products such as alkanes, alkenes, alkadienes, aromatics, carboxylic acids, etc. The purpose of this route is to obtain high-value fuel products from biomass by thermal and catalytic methods. Pyrolysis of triglycerides was found to be a potential option for the production of biodiesel [72]. This process is not widely accepted due to huge ash and carbon residue content (79% carbon in the case of soya bean oil), large input energy and high pour point of the final fuel product [73].

Microemulsions are defined as transparent, thermodynamically stable colloidal dispersions, in which the diameter of the dispersed-phase particles is less than one-fourth of the wavelength of visible light [74]. The flow behaviour of biofuel in the application of a diesel engine needs to be simplified, which was successfully solved with this technique.

Transesterification of oil to its corresponding fatty ester is one of the most promising techniques involved in the synthesis of biofuel. Basically, in transesterification reaction oil reacts with alcohol in the presence of some catalysts to yield fatty acid alkyl ester and

glycerol [58, 75, 76]. The catalysts that are primarily used in transesterification reaction in biofuel synthesis are alkali, acid and enzymes. Alkali catalysts are considered suitable catalysts for the transesterification reaction.

Microwaves are electromagnetic radiations that represent a non-ionising radiation that influences molecular motions such as ion migration or dipole rotations, but does not alter the molecular structure. The frequencies of microwave range from 300 MHz to 30 GHz, generally a frequency of 2.45 GHz is preferred in laboratory applications. The microwave process can be explained for the biodiesel production with transesterification reaction: the oil, methanol and base catalyst contain both polar and ionic components [77]. Microwaves activate the smallest degree of variance of polar molecules and ions, leading to molecular friction, and therefore the initiation of chemical reactions is possible. When the reaction is carried out under microwaves, transesterification is efficiently accelerated in a short reaction time. As a result, a drastic reduction in the quantity of by-products and a short separation time are obtained with high yields of highly pure products [78].

Ultrasonic waves are energy applications of sound waves that are vibrated more than 20000 per second. Ultrasonic processing of biodiesel involves the following steps: (i) mixing vegetable oil with the alcohol (methanol or ethanol) and catalyst, (ii) heating the mixture, (iii) the heated mixture is sonicated inline and (iv) glycerine separation by using centrifugation [79].

In all the above methods, four steps are involved for the biofuel synthesis in general. In the first step, transesterification reaction takes place between reagents and reactants under the controlled conditions. The resultant slurry is settled and centrifuged for phase separation in the second step. Thirdly, in an evaporator or a flash unit unreacted alcohol, the formed biofuel is sent to separate alcohol. Neutralisation and distillation of biofuel from other unwanted components such as catalyst and unreacted triglyceride is carried out in the fourth step.

The two most commonly used reactors for the commercial production of biofuel are batch-mode process and continuous flow reactor. In the batch-mode process, there is no flow of reactant and product of the reagents in and out of the reactor in a specific period of time, [80] while in the continuous flow process, feedstock is continuously fed into the continuous-mode reactor while product stream leaving the system.

Many reactors for the biodiesel production are available. These reactors are based on the operational parameter with respect to chemical properties of reactants, reagents and products as well as physical parameters of procedure [81]. Thus, cost-effective and eco-friendly biofuel production technologies should be adopted to make this biofuel more competitive against the traditional fuels used. Different transesterification reactors are listed in Figure 1.8, which are finally analysed from the various angles. Merits and limitations of each reactor open up a new area of research.

1.6 Biofuel Properties

Properties of biofuel will indicate whether it is suitable or not for the performance, emission and life for the desired application. The major deviation in the range of standard parameters of biofuel could damage the engine in which it is used. An acceptable and

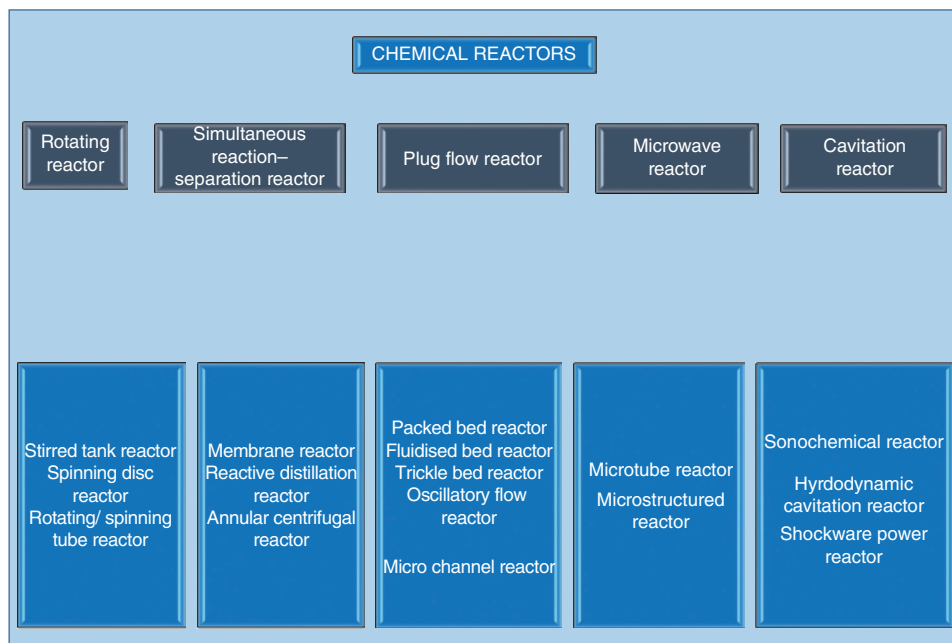


Figure 1.8 Types of reactors.

persistent properties of biodiesels can only be guaranteed by relating to the biodiesel quality standards. It is essential to watch the quality during the biodiesel manufacturing procedure, from the feedstock to the delivery stations to accomplish this goal. The composition and nature of the feedstock used for the production strongly impact the physicochemical properties of biofuels. Blending, testing, storage and distribution should be involved in quality assurance and monitoring. Usually, the differences in biofuel properties listed in Table 1.1 are seen in oxidation stability, cetane number, iodine value, viscosity and density [105, 106].

Acceptability of biodiesel by various sectors depends on its socioeconomic and environmental impacts. Adverse cold flow properties, poor oxidation stability, corrosive and acidic nature, and degradation tendency of biodiesel present it as a non-compatible system. A vast area is opened for the R and D sector to further improve its properties and make it compatible with automotive materials.

1.7 Socioeconomic and Environmental Impact

The development of world economy is restricted because of one of the important factors, i.e. shortage of energy. Public awareness, opinion and knowledge could contribute to the social acceptance of biofuels [107]. The current surge in biofuel investments and manufacturing capacities is determined by the potential of multiple social, economic, ecological, and geopolitical aids. From a broader view, there are mainly three motives behind the promotion of biofuel in the society (Figure 1.9). The socioeconomic and environmental impact

Table 1.1 Specifications of biodiesel.

Property	ASTM D6751-12				EN 14214:2012			
	ASTM D975-08a	2-B	1-B	Test		EN 590:2004		
Flash point [82], min	No 1D 38 °C No 2D 52 °C	93 °C		D93	55 °C	EN 22719	101 °C	EN ISO 2719
Water and sediment [83], max	0.05% vol.			D2709				
Water, max		0.050% vol.		D2709				
Total contamination, max								
Distillation temperature [84] (% vol. recovered)	90%: 1D 288 °C max 2D 282–338 °C	90%: 360 °C max		D1160	65%: 250 °C min 85%: 350 °C max	EN ISO 12937 EN 12662 EN ISO 3405	500 mg/kg 24 mg/kg	EN ISO 12937 EN 12662
Kinematic viscosity [85]	1D 1.3–2.4 mm ² /s 2D 1.9–4.1 mm ² /s	1.9–6.0 mm ² /s		D445	2.0–4.5 mm ² /s	EN ISO 3104	3.5–5.0 mm ² /s	EN ISO 3104
Density [86]								
Ester content [87]	5% vol. max			EN 14078	820–845 kg/m ³	EN ISO 3675 EN ISO 12185	860–900 kg/m ³	EN ISO 3675 EN ISO 12185
Ash [88], max	0.01% wt.			D482	5% vol. max FAME	EN 14078	96.5% min	EN 14103
Sulfated Ash [89], max		0.020% mass		D874	0.01% wt.	EN ISO 6245		ISO 3987
Sulphur [90], max (by mass)	1D and 2D: S15 15 mg/kg S500 0.05% S5000 0.50%	Two grades: S15 15 ppm S500 0.05%		D5453 D2622 D129 [2]	Two grades: 50 mg/kg 10 mg/kg	EN ISO 14596 EN ISO 8754 EN ISO 24269	10.0 mg/kg	EN ISO 20846 EN ISO 20884 EN ISO 13032

(Continued)

of biofuel varies widely based on the specific condition of the country. Political support or strategy is evolved out of or by the combination of those three areas.

The profit and cost for biofuel have a tendency to differ across commodities, landscape and business models. The main positive influence of the countries is income, rural development, employment and energy security [108]. Energy security refers to the capacity of nation to access the energy resources desired to sustain its national power. The evaluation of the economics of renewable energy development included the estimation of the resulting economic costs and benefits to any country including (i) cost of electricity, (ii) direct and indirect impacts on jobs, income and economic output, and (iii) renewable liquid fuel price impacts. The benefits of bioenergy comprise support of traditional trades, the financial expansion of rural civilisations and rural diversification. The cost of biomass conversion includes factors such as the scale of operation, types of biomasses, conversion process and the location of feedstock. The relative cost of biofuel will also depend on the accessibility of the alternative energy possibilities. In the development of biofuels, trade barriers, price interventions and financial support played a critical role. Biofuel chain (harvesting, production, transportation, etc.) will generate employment opportunities and increase people's income [109]. The socioeconomic effect of biofuel includes its impact on food security, supply and accessibility. Moreover, the reuse of unrestrained crops imitates the idea of a recycling economy, advances the efficacy of resource usage, and thus protects resources associated with the production method. The first-generation biofuels are considered to be cost-effective, while the second-generation biofuels cost is indeterminate and differ with the production and conversion process. Feedstock for second-generation biofuel would reduce the cost by 50% for production than the use of corn and sugar-based feedstock.

Biofuels have the strongest association with agricultural markets and residues as they are formed from agricultural supplies and have the utmost ability to influence food production and values [110], while next-generation biofuels derived from lignocellulosic biomass and photosynthetic algae may have rarer straight relations to food production systems. Biofuel is explored so much because of its advantage on environment. The reason being biofuel is carbon neutral, i.e. the amount of carbon released when it is burned is equal to the amount of carbon utilised in the photosynthesis of plants, thereby reducing the GHG gas emission in the environment. Environmental impact includes issues such as loss of biodiversity, degradation of soil and water resources quality. Environmentally benign biofuel-making procedure is projected to have little energy involvements in all steps starting from agriculture to processing of plants and manufacturing of biofuels with higher energy balance and better engine performance. Ecosystem is affected significantly with feedstock production for biofuel, either by enhancing biodiversity or intimidating the natural habitat and species. Some feedstock like sugar beet has higher impact on aquatic ecosystem than maize or

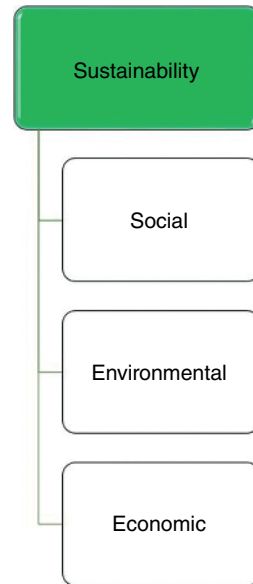
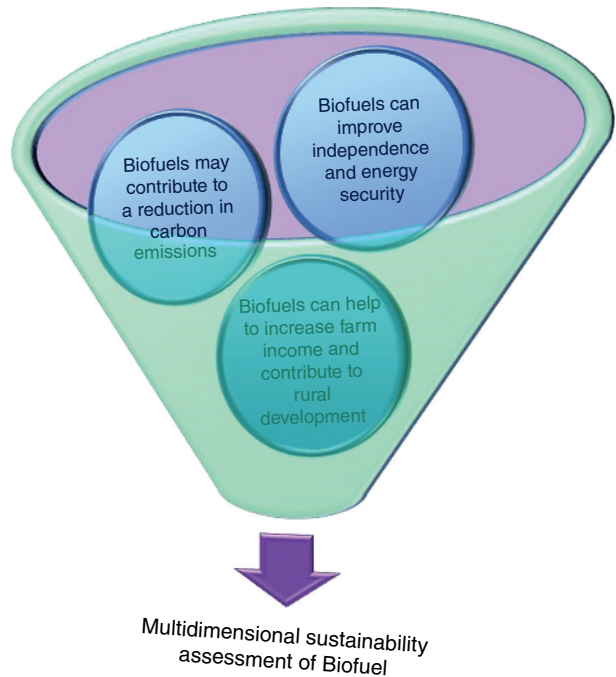


Figure 1.9 Socioeconomic and environmental impacts of biofuels.

Figure 1.10 Multidimensional sustainability assessment.



wheat so that its monoculture is preferred compared to others. A number of tasks are placed for biofuel and managing the soil fertility. First is the possibility of recycling for small organic and plant nutrients. Current agricultural practices (in particular in developing countries) for soil management depend on the crop wasted. Secondly, feedstock nutrients can be retrieved during land conversion processes and applied to the crop field for biofuel production. Finally, hydrological effects are also important. Some bioenergy crops require the same amount of water irrigation as food crops (i.e. sugar cane). Best agricultural practices should avoid water infiltrations of water wastes to guarantee an efficient growth of bioenergy crop. Economic and environmental credibility of coproducts is essential to completely justify that investments in biofuel sectors are profitable and will meet the present energy demands and also curb greenhouse emissions (Figure 1.10). Thus, multidimensional sustainability assessment is very essential for a sustainable energy future.

1.8 Conclusion

Fossil fuel being limited, i.e. non-renewable energy source, its combustion causes side effects on the environment; thus, an alternative has to be considered. The usage of biofuels is projected to contribute to the energy maintenance and global warming reduction [111]. Biofuel is a renewable energy that can be used again and again. More than two-thirds of the total renewable energy mix is accounted by the bioenergy. The centre stage is gained by biofuel as human activities are rising. The high reliance and burden on limited fossil fuels will be shifted due to the worldwide call to look into renewable eco-friendly fuel carriers.

Biofuel is expected to increase the overall economy of the country. It benefits the society by providing employment, rural development and energy security. The second-generation cost is indeterminate, but the production cost can be reduced by 50% as compared to that of first generation. Biofuel is used because of its environmental benefits. It has the capacity to reduce the GHGs and can mitigate many environmental issues. The production of feed-stock for biofuel has an impact on the fertility of soil, water usage and biodiversity. It is important to have the biofuel of the desired properties, which will make it efficient for use. There are some standard values for the properties of biofuel, which are given by the agency that makes its accomplished for use. With a diverse range of potentially renewable energy resources, the idea and expected benefits developing from the usage of biofuels are inspiring; subsequently, in demand to contribute to a sustainable and energy secure future, they must be taken into consideration.

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